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14. ABSTRACT Particle image velocimetry systems have been acquired for acquisition of instantaneous images of unsteady separated flows. Images are acquired at a rate much higher than the characteristic frequency of these flows. This instrumentation has been employed to acquire and construct: (i) planar images; (ii) space-time volume images; and (iii) spatial volume images. Processing techniques allow determination of the flow topology, vorticity, and spectra and cross-spectra, based on simultaneous records at thousands of locations in the flow field. Collaboration with the Computational Sciences Branch at the Air Force Research Laboratory has yielded extensive experimental- numerical comparisons. Three doctoral students at Lehigh University have employed the acquired instrumentation. The overall objectives during specification of the instrumentation were to: optimize space-time imaging capabilities using different types of cameras with specific ranges of sensitivity and frame rate; attain a high rate of repetition of the pulsed laser system; and maintain compatibility with laser synchronizer systems and host computers deployed at different experimental locations in our laboratories. To meet these objectives, it was necessary to account for the rapidly evolving technologies associated with each of the aforementioned items. All objectives have been accomplished, and experimental advances have been already made on several projects.					
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FINAL REPORT

SPACE-TIME IMAGING SYSTEMS

AFOSR Grant #FA9550-07-1-0517

Grant period: 15 June 2007 to 14 December 2008

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1. PROJECT SUMMARY

Particle image velocimetry systems have been acquired for acquisition of instantaneous images of unsteady separated flows. Images are acquired at a rate much higher than the characteristic frequencies of the major events in these flows. This instrumentation has been employed to acquire and construct: (i) planar images; (ii) space-time volume images; and (iii) spatial volume images. Processing techniques allow determination of the flow topology, vorticity, and spectra and cross-spectra, based on simultaneous records at thousands of grid points in the flow field. Collaboration with the Computational Sciences Branch at the Air Force Research Laboratory has yielded extensive experimental- numerical comparisons. Three doctoral students at Lehigh University have benefitted from the acquired instrumentation.

The specific objectives during acquisition of the instrumentation were to: optimize space-time imaging capabilities using different types of cameras with specific ranges of sensitivity and frame rate; attain a high rate of repetition of the pulsed laser system; and maintain compatibility with laser synchronizer systems and host computers deployed at different experimental locations in our laboratories. To meet these objectives, it was necessary to account for the rapidly evolving technologies associated with each of the aforementioned items. All objectives have been accomplished, and experimental advances have been already made on several projects.

2. ACQUIRED INSTRUMENTATION

The following the instrumentation has been acquired during this program. Nearly all components were purchased from Thermo-Systems Inc. (TSI):

TSI Model PIV00513

Litron Nano L 50-100 PIV Laser, 50 mJ/pulse 532 nm at 100 Hz.

Twin Oscillator/Single HGSA (One) [\$75,000]

TSI Model PIV00538

Laser Mounts and Alignment Kit for Litron Lasers (One) [\$3,500]

TSI Model 610021-SOL

Laser Light Sheet Optics for PIV Laser (One) [\$3,900]

TSI Model PIV00641

Motion Pro X5 Plus 4 Mpixel High Frame Rate Camera (One) [\$37,500]

TSI Model PIV00616

Camera Plus Option Upgrade (One) [\$5,000]

TSI Model 630057

PowerView Plus 2MP 1.6k x 1.2k Pixel Resolution, High Quantum Efficiency, Low Noise Digital CCD Camera (Three) [\$40,975]

TSI Model 610035

Laser Pulse Computer Controlled Synchronizer (Two) [\$20,125]

TSI Model 1090291

Camera Mount Scheimpflug (Two) [\$5,900]

TSI Model 900105

Frame Grabber PC-CameraLink 64-bit [\$5,500]

TSI Model PIV00603

Computer PIV-Intel Dual Core Xeon, 3.0 GHz Workstation (Three) [\$17,400]

(Note: The above prices for TSI components were adjusted to account for shipping and handling, and credit for returned, out of date TSI cameras (\$8,665).)

Best Buy and NewEgg: External 500 GB Hard Drives (Twelve) [\$1,615]

Gilmmore Kramer and Buyonlinenow: Instrument Carts (Two) [\$688]

The total amount of the original award was \$214,470. Purchase of the foregoing instrumentation was at a total cost of \$208,438, due to the fact that the vendor of the instrumentation unexpectedly provided credit for out-of-date (used) camera systems that were returned to them.

3. RESEARCH ADVANCES WITH ACQUIRED INSTRUMENTATION

Since the instrumentation has been acquired, research advances have been made on several projects: (i) flow structure past a three-dimensional wing in stimulated steady flight; (ii) flow structure due to high frequency perturbations of a three-dimensional wing; (iii) unsteady flow patterns on a wing (flat plate) undergoing flapping motion; (iv) three-dimensional flow patterns past a nominally two-dimensional wing having a sinusoidal leading-edge; (v) flow structure along a delta wing at high angle-of- attack, with straight and sinusoidal leading-edges; and (vi) quasi-two-dimensional and three-dimensional flow along a rectangular cavity undergoing acoustically-coupled oscillations. All of these investigations have made use of the unique features of the acquired instrumentation, and provided new insight into a range of phenomena associated with unsteady aerodynamics. In the following, a representative investigation, corresponding to the foregoing item (ii), is summarized.

Figure 1 shows the flow structure on a three-dimensional wing subjected to small-amplitude perturbations. The wing is a scale model of the 1303 UCAV. Investigation of this configuration at low Reynolds number provides insight into the range of issues associated with micro aerial vehicles.

As indicated in the patterns of instantaneous vorticity in the left column of Figure 1, perturbations are very effective for inducing a vorticity layer along the surface of the wing, when the excitation is at a subharmonic of the inherent instability frequency, i.e., $f_o/2$. This pattern of vorticity contrasts with that from the stationary wing, which remains fully separated. Corresponding patterns of time-averaged streamlines, indicated in the right column of Figure 1, indicate that the streamline topology goes from a fully-stalled state to an essentially attached state, except for a small-scale separation bubble located in the leading-edge region, when perturbations are applied.

It should be noted that nearly all of the aforementioned investigations (i) through (vi) are compatible with the research aims of colleagues at AFRL. For example, investigation (i), which addresses the flow structure past a stationary wing at various values of Reynolds number and angle-of-attack, has been the focus of extensive calculations by colleagues at AFRL, Scott Scherer, Miguel Visbal, and Ray Gordnier. Time-averaged flow patterns have been directly compared, and preparation of a joint manuscript is in progress.

ERADICATION OF STALL VIA SMALL AMPLITUDE PERTURBATIONS

Quantitative cinema imaging reveals flow physics of recovery of unstalled state from fully stalled flow past a three- D wing at high angle of attack

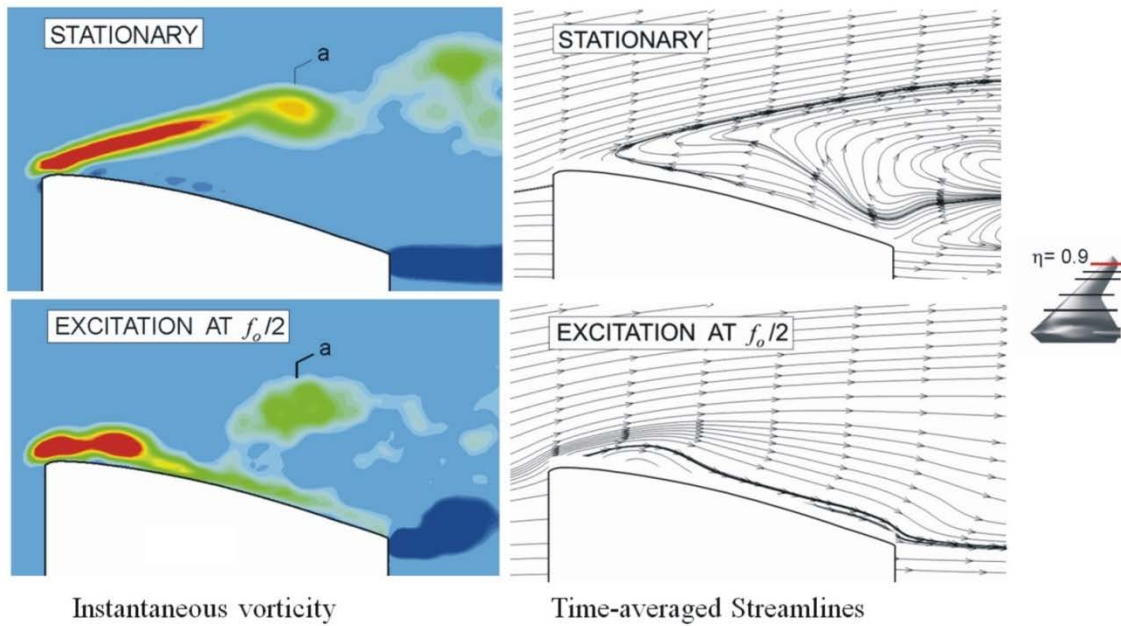


Figure 1: Small perturbations (one-half degree) of angle-of -attack at the subharmonic of the inherent instability frequency of the shear layer yields fundamental changes of both instantaneous and time-averaged patterns (Yilmaz and Rockwell, 2008)